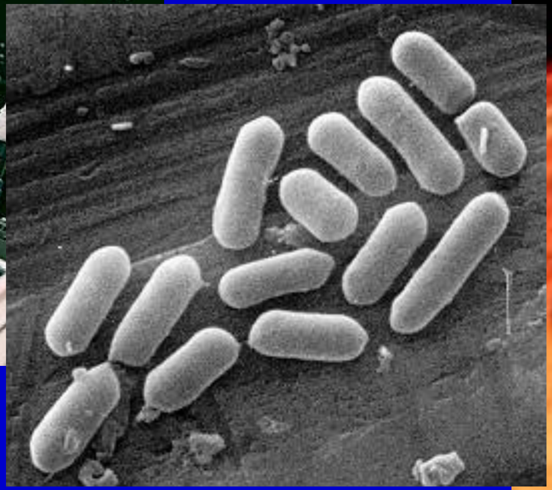
Current Trends of High-Throughput Methods for Planetary Protection Requirements Associated with a Human Mission

F. Karouia[1,3], K. Peyvan[2], O. Santos[1], and A. Pohorille[1]

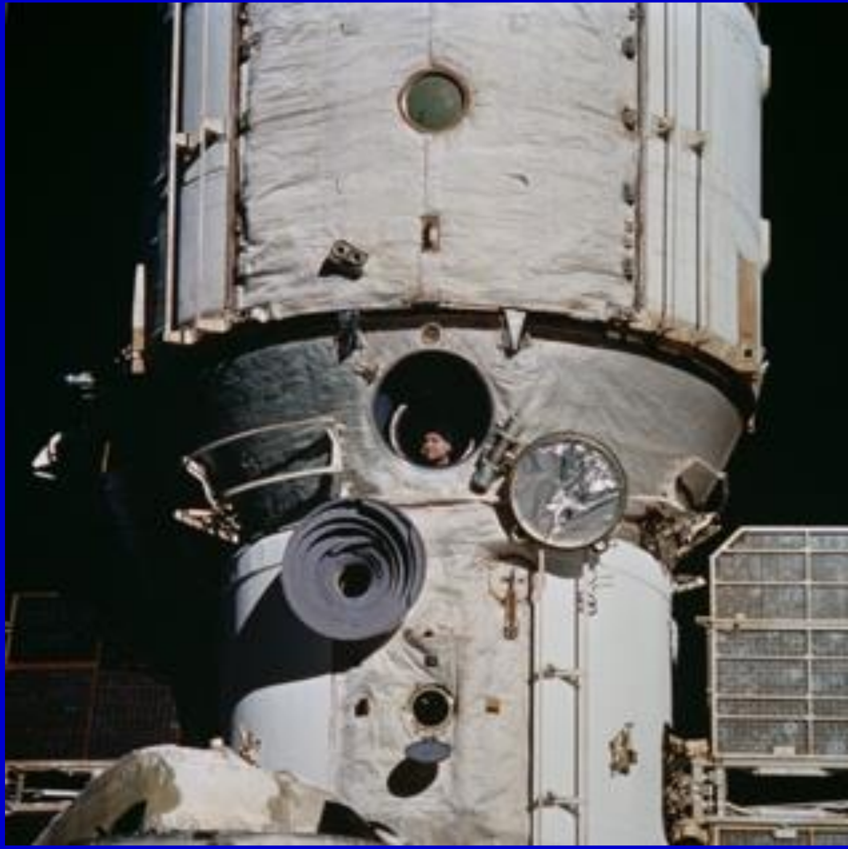
[1]NASA Ames Research Center, [2]Peyvan Systems, [3]University of California San Francisco



Planetary Protection Workshop, NASA Ames, 03/24-26/15

Outline

- Disclaimer
- What is the Focus of this Presentation?
- What are the Types of Technology/Methods Currently Available?
- What High-Throughput Methods are Suitable for Planetary Protection?
- Insights into the trade-off for the right technology developments
- Recipe for deployment for *in-situ* Omics technologies
- Acknowledgements



PP Requirements Associated with Human Mission

- What is the context of the PP workshop?
  - Capture the current state of knowledge in the 3 different areas: 1) microbial and human health monitoring, 2) technology and operations for contamination control, and 3) Natural transport of contamination on Mars
  - And identify additional research to appropriately inform PP requirements for the human exploration on Mars
- This presentation will focus on study area 1: microbial and human health monitoring in general and in particular the **type of technology needed for**:
  - The Monitoring growth and survival of human & habitat associated microbial populations in space environments
    - Microbiome research and the ability to detect extraterrestrial perturbations if any (both in-flight and on Mars or another target)
    - Crew health and habitats microbiome impacts from Mars material exposure
- and **which technologies are amenable for adaptations for space applications?**

Spacecraft Microbial Systems

Spacecraft Microbial Systems

Spacecraft have three types of microbial ecosystems:

– The Good: Intentionally introduced (life support system, ISRU, Probiotics)

Spacecraft Microbial Systems

Spacecraft have three types of microbial ecosystems:

- The Bad: Contaminants that have colonized the spacecraft/habitat

Spacecraft Microbial Systems

Spacecraft have three types of microbial ecosystems:

- The Ugly: Anthropogenic (Associated with Human)

Spacecraft Microbial Systems

Spacecraft have three types of microbial ecosystems:

- The Good: Intentionally introduced (life support system, ISRU, Probiotics)
- The Bad: Contaminants that have colonized the spacecraft/habitat
- The Ugly: Anthropogenic (Associated with Human)

- Extraterrestrial

What are the Types of Technology/Methods Currently Available?

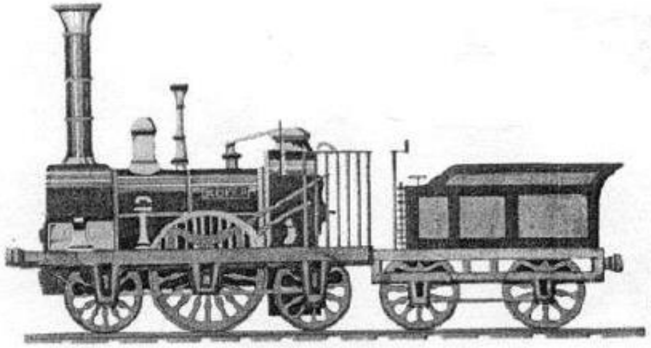
- Bioburden:
  - Cytological Methods: (#1019)
    - Epifluorescent Microscopy
    - Live/Dead cells by propidium staining
    - Flow cytometry
  - Biomarker Methods:
    - Limulus Amebocyte Lysate Assay (LOCAD)
    - ATP Bioluminescence Assay (JPL)

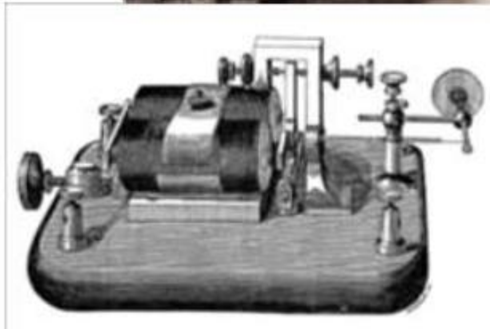
- Biodiversity:
  - Amplification based methods:
    - NASBA (#1031)
    - RT-PCR
    - Real-Time PCR
  - Microarrays (GEMM)
  - Sequencing
  - Mass-Spectrometry
  - Proteomics

Reference: Preventing the forward contamination of Mars. NRC 2006.

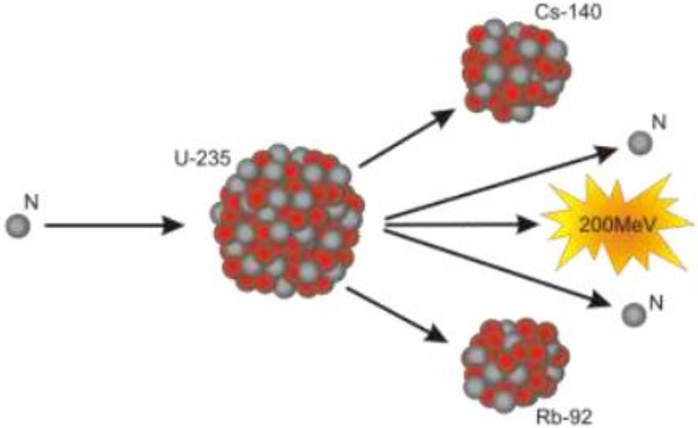
The 19th Century: The Age of Engineering

Fig. 327.

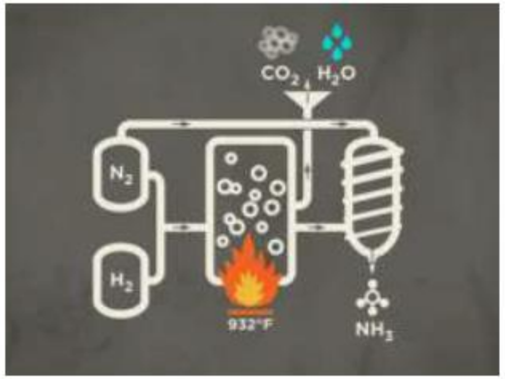


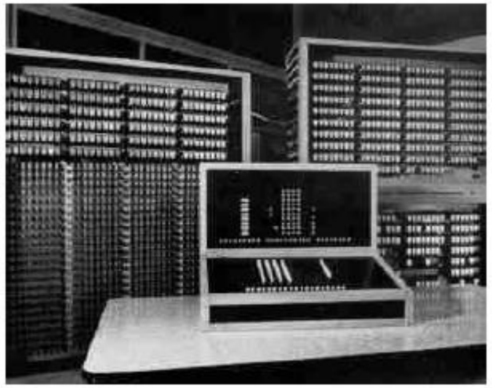


The 20th Century: The Age of Chemistry and Physics



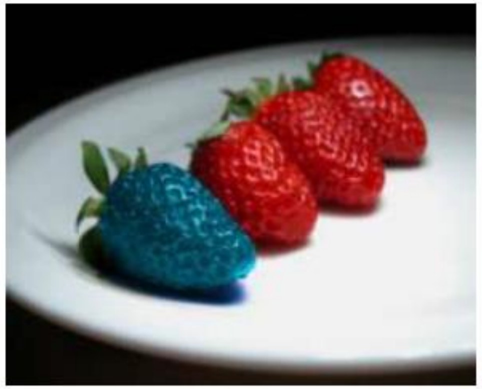
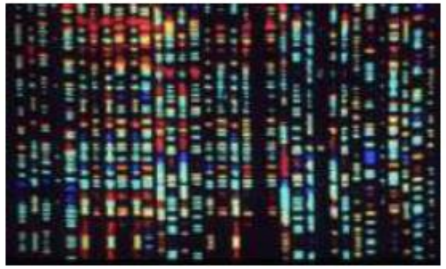
$$E = m{\cdot}c^2$$

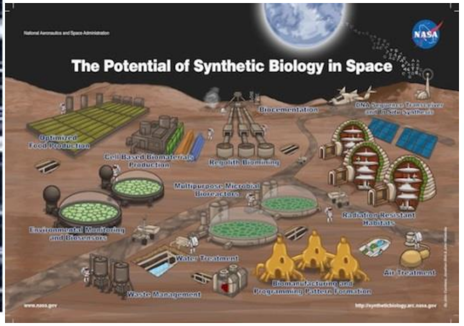


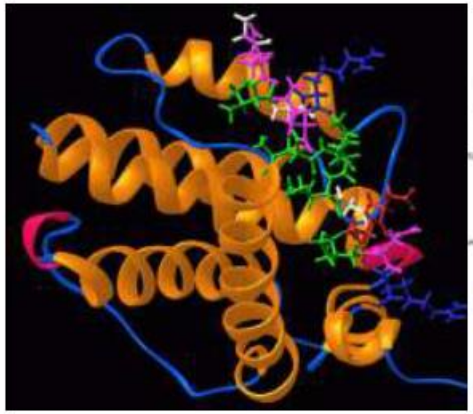
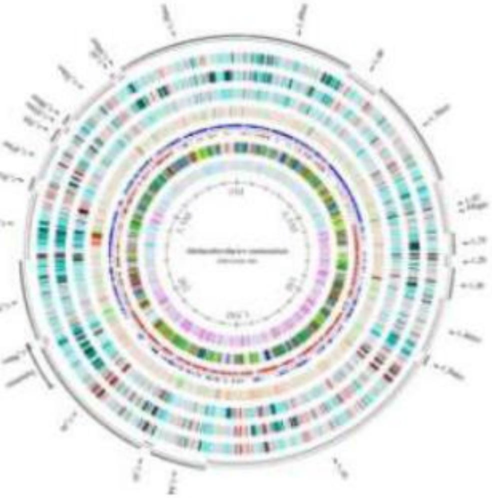


The 21st Century: The Age of Biology





Rationale for High-Throughput Methods

- Terrestrial organisms traveling beyond their planet of origin encounter challenging environments characterized by multiple stresses.
- To advance space biology it is not sufficient to identify different physiological effects of space-related stressors on living systems. What is required is to understand how these stress factors impact organisms at cellular, or even molecular level.
- As a results of recent, revolutionary changes in biology, we are now equipped with a set of tools that provide information about living systems far exceeding anything that was available only two decades ago.
- This changed the old reductionist paradigm in biological studies to an integrative one and gave raise to the new field of systems biology.

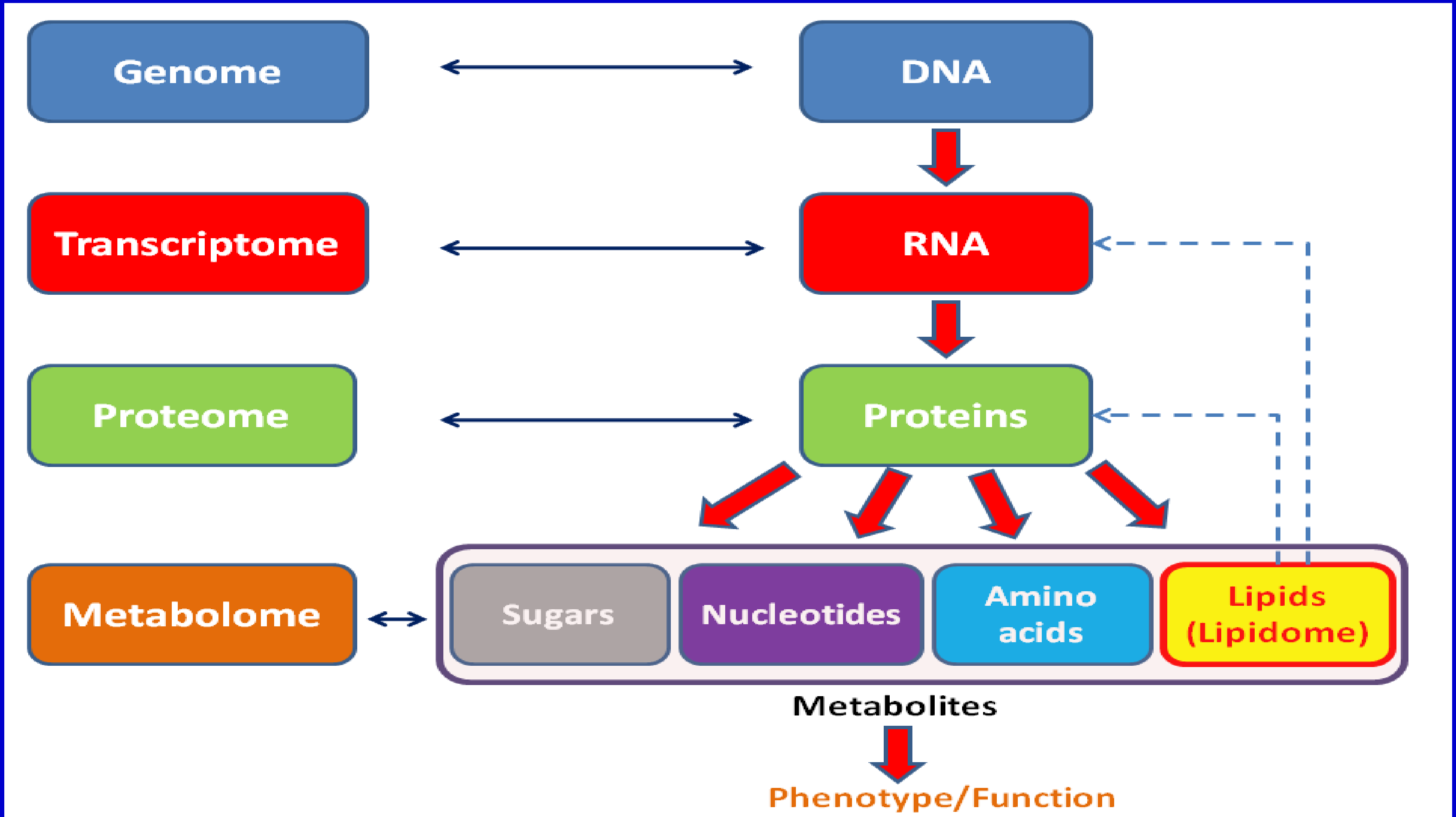
Biological Research in Space

- Planetary Protection:
  - Monitor and Identify Terrestrial Contaminants
- Biological System to Support Exploration:
  - Life Support Systems and *In-Situ* Resources Utilization
- Biomedical and Physiological Studies:
  - Effects of Space on Humans and Animal Models
- Basic science:
  - How Organisms Survive and Manage Stresses due to Exposure to Space environments

High-throughput Omics Technologies for Space Applications

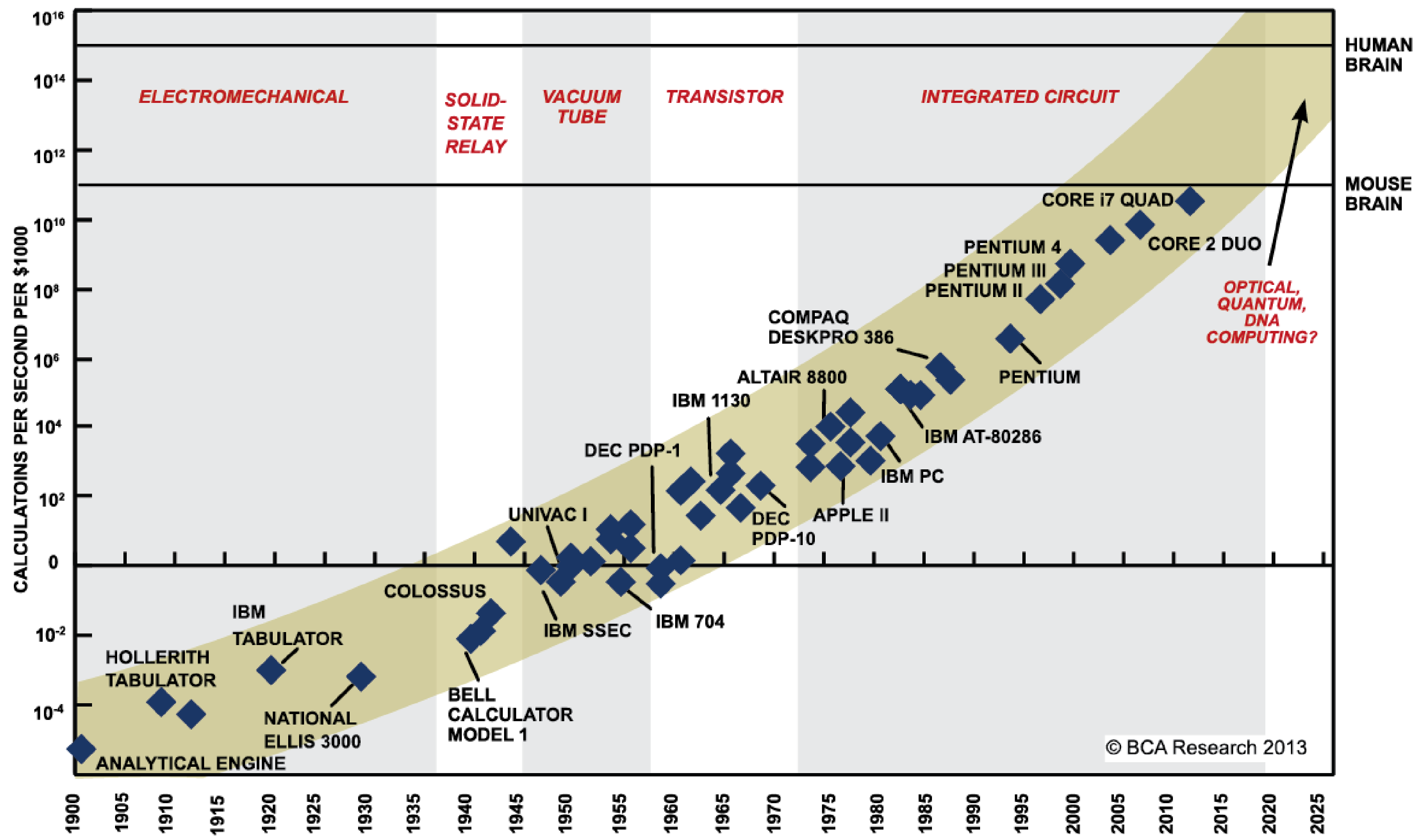
- high-throughput methods would leverage our understanding in:
  - Behavior, in particular metabolism and regulation (including development),
  - Genetic adaptations, and
  - Identification of microorganisms

"Omics Research"



Science Based Medicine 2011

Lag Phase of Space Research



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

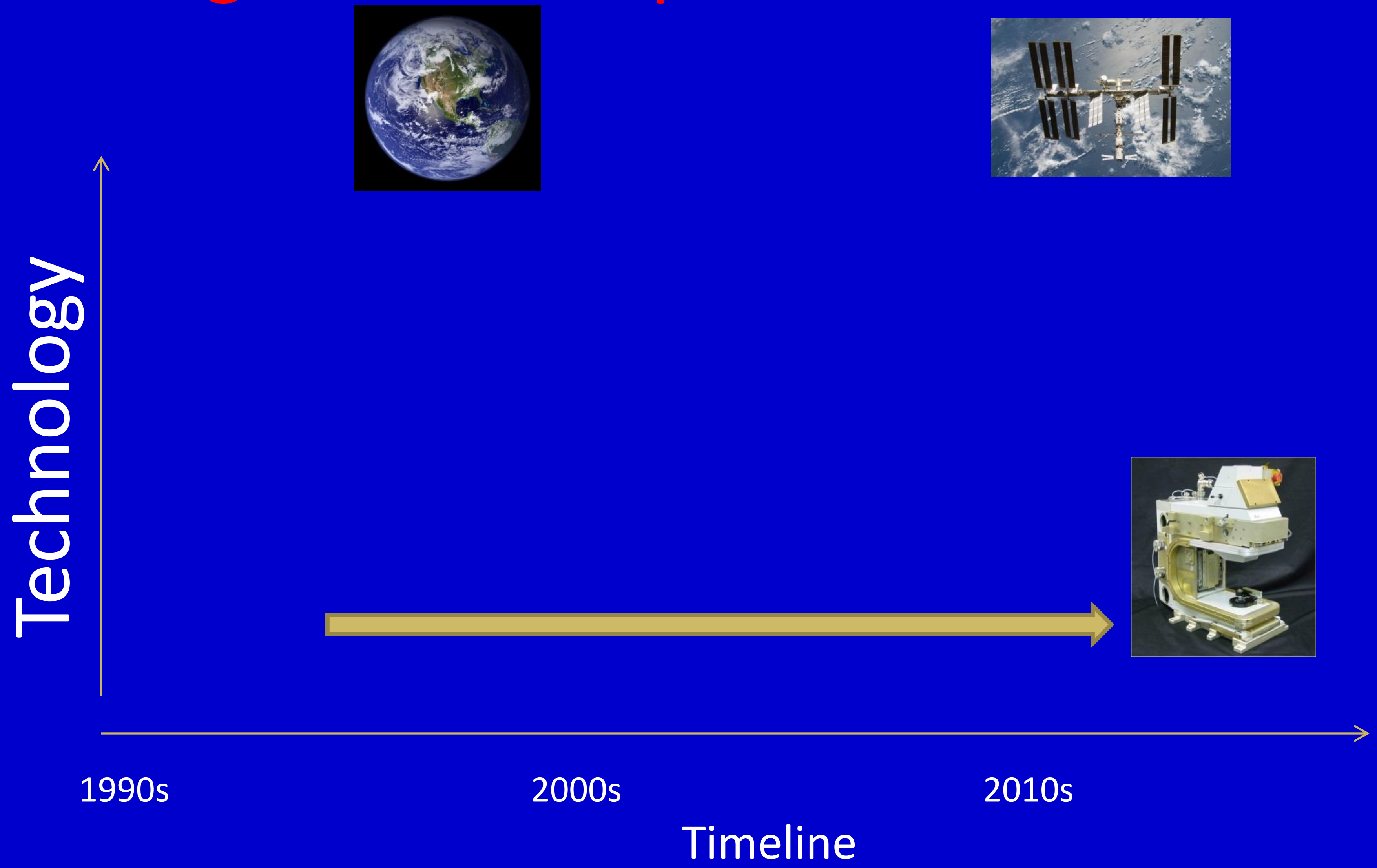
Lag Phase of Space Research

Technology

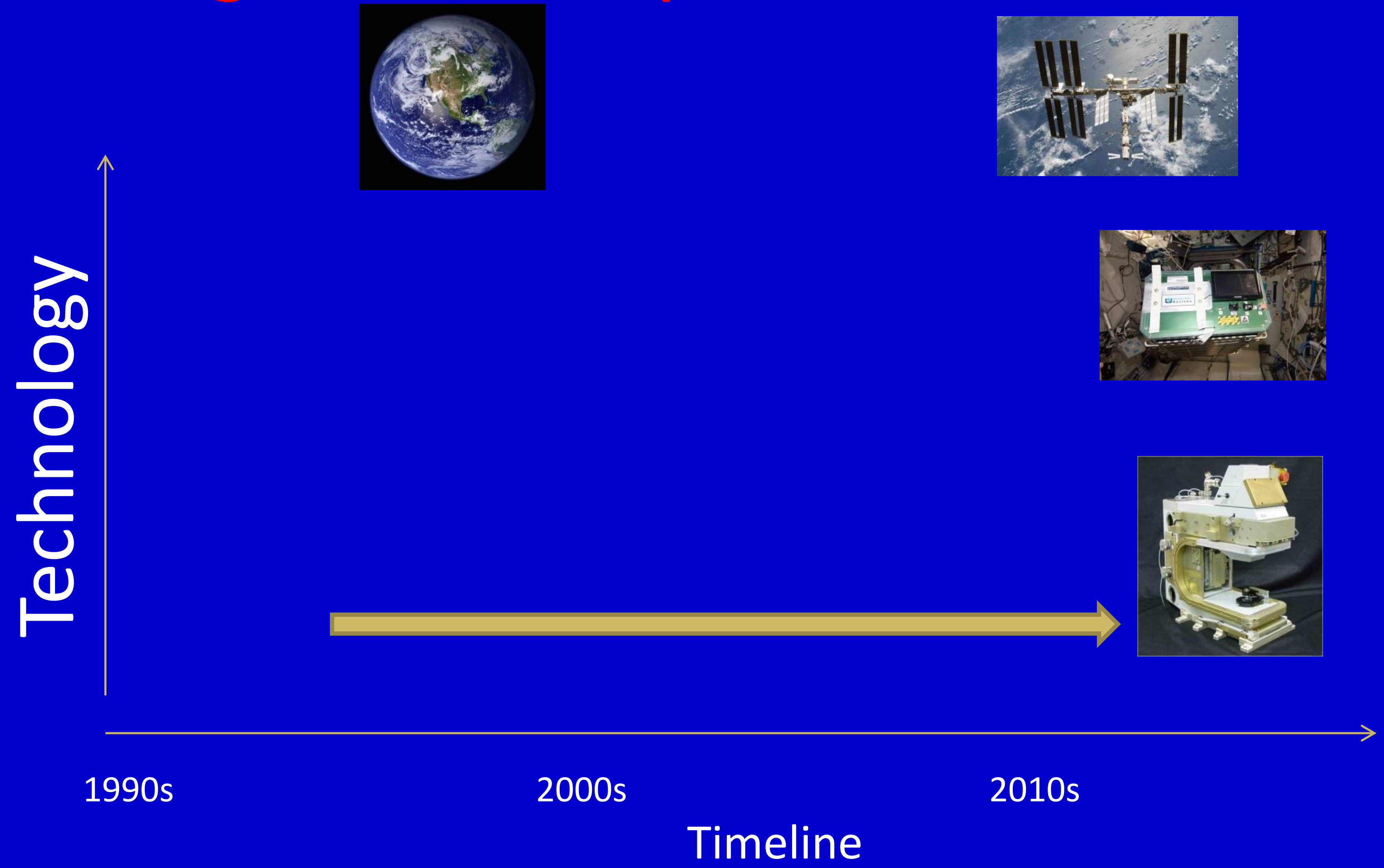
1990s 2000s 2010s

Timeline

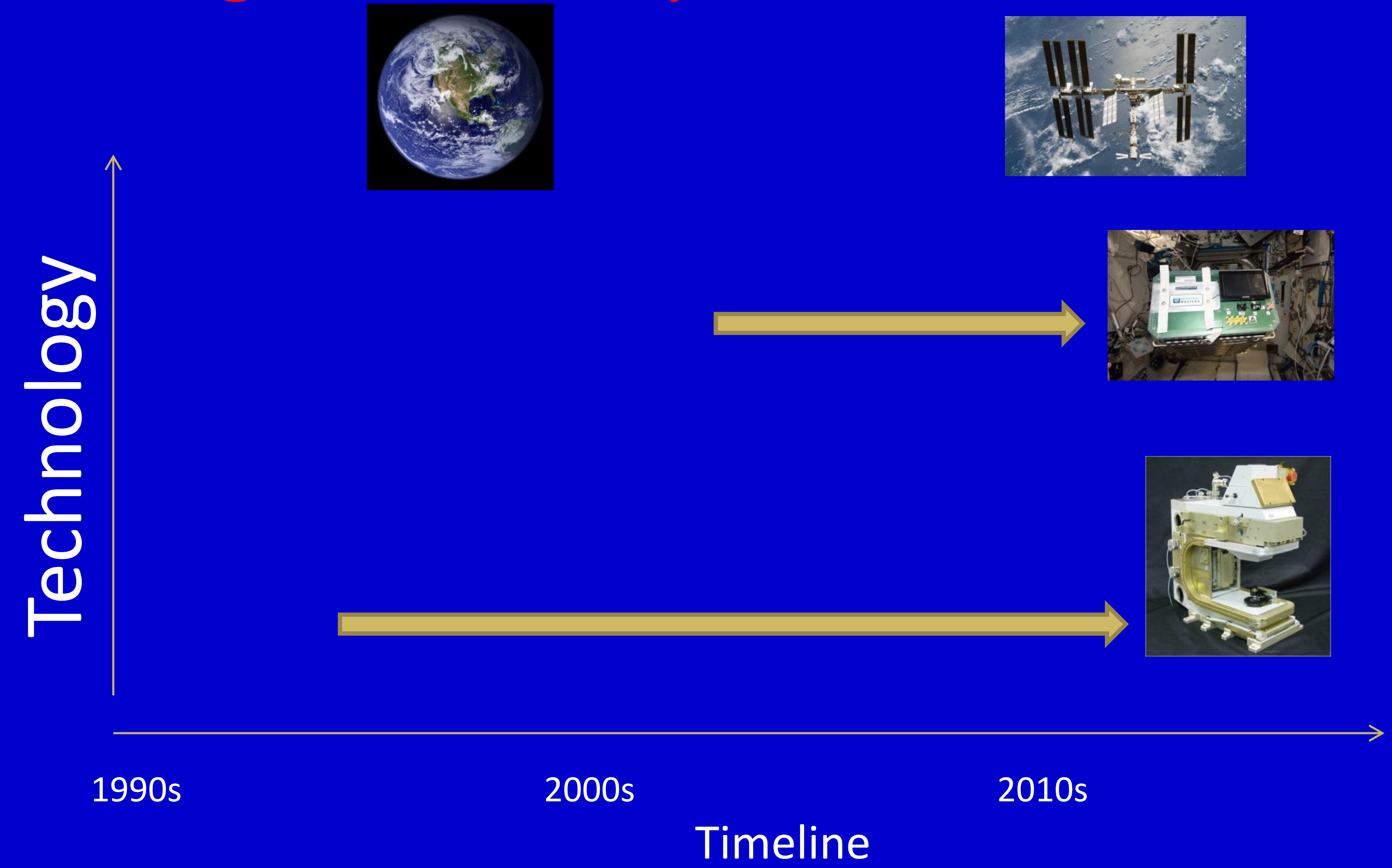
Lag Phase of Space Research



Lag Phase of Space Research



Lag Phase of Space Research



Lag Phase of Space Research

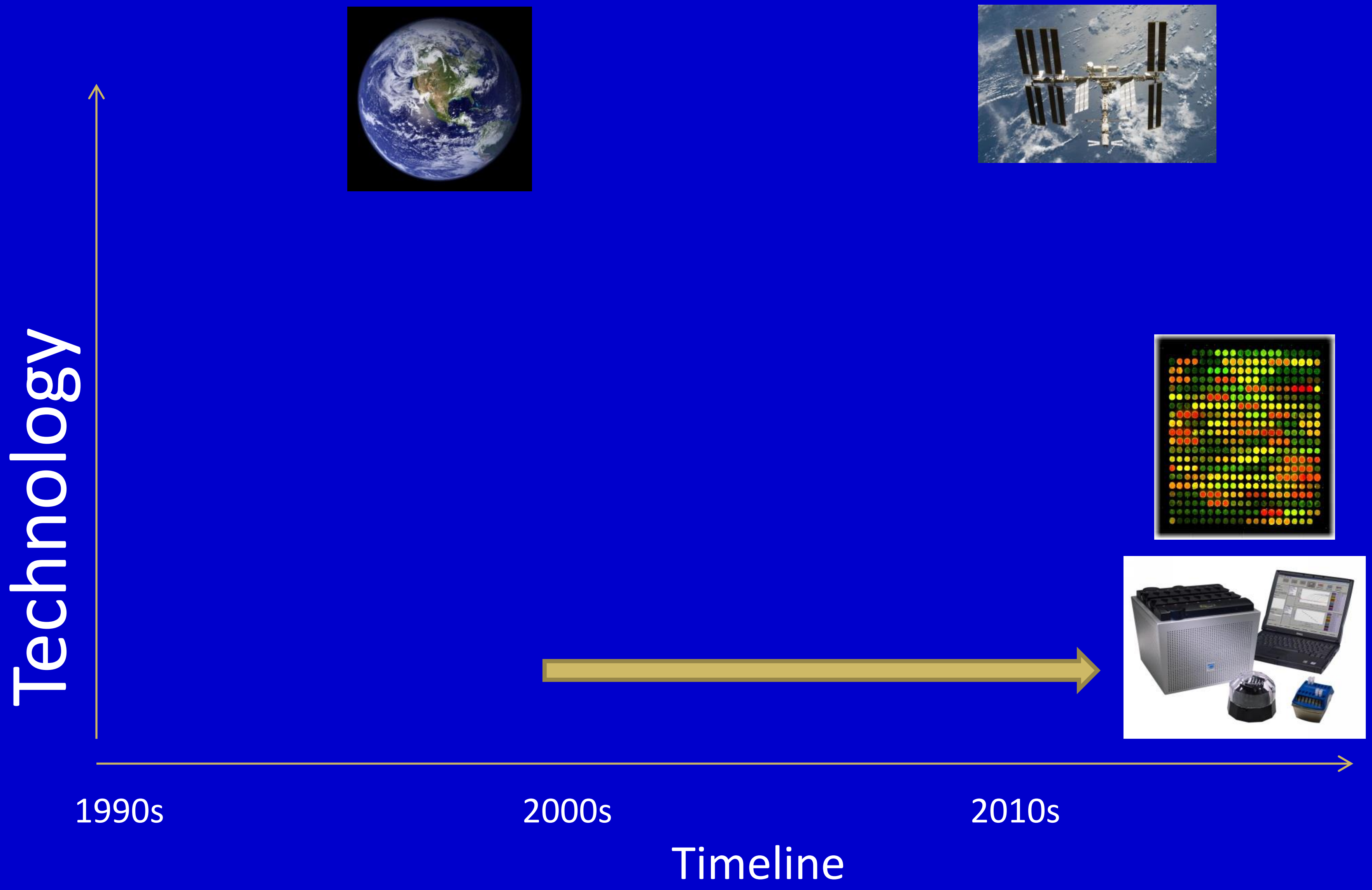
Lag Phase of Space Research

Technology

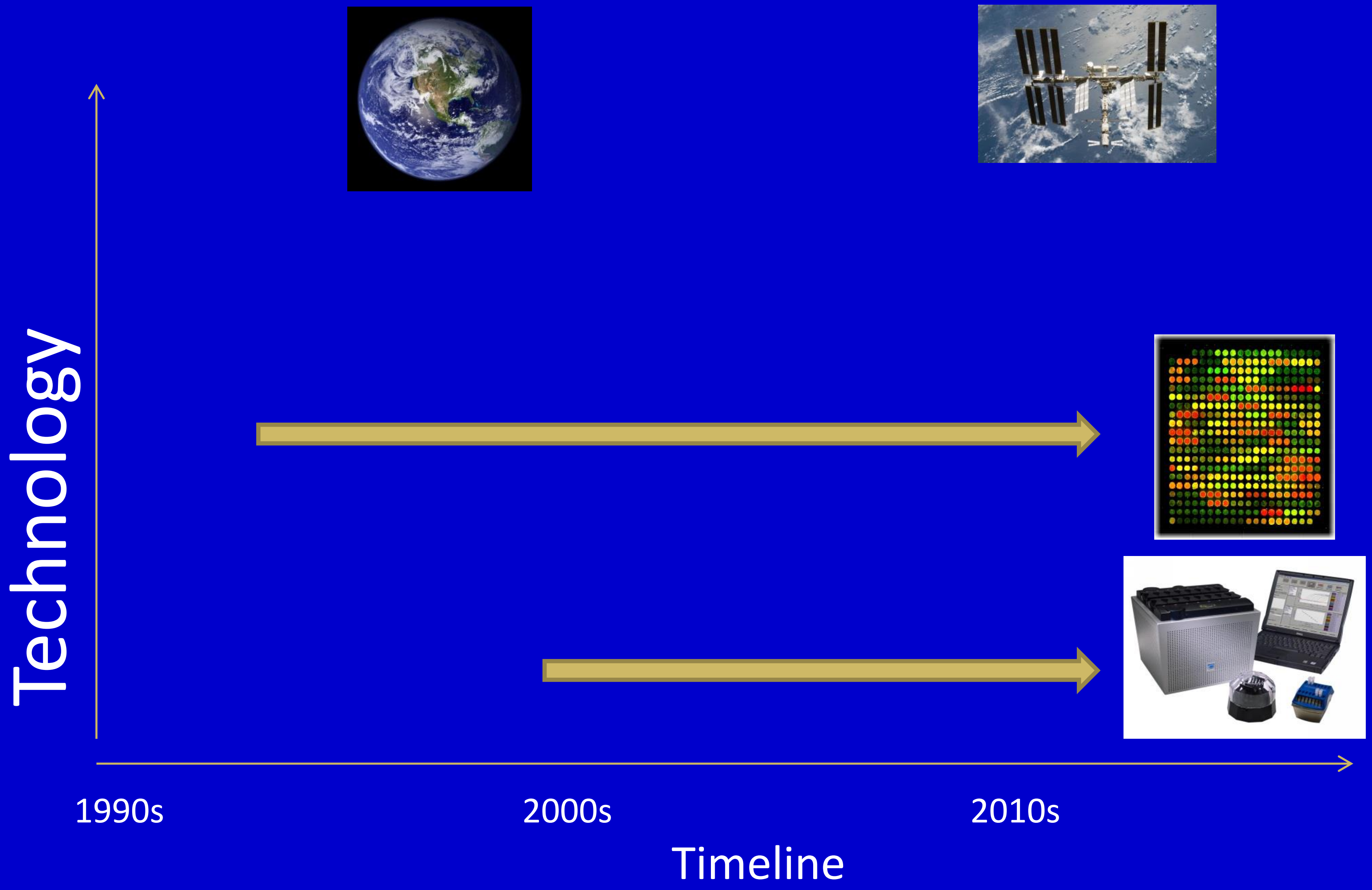
1990s 2000s 2010s

Timeline

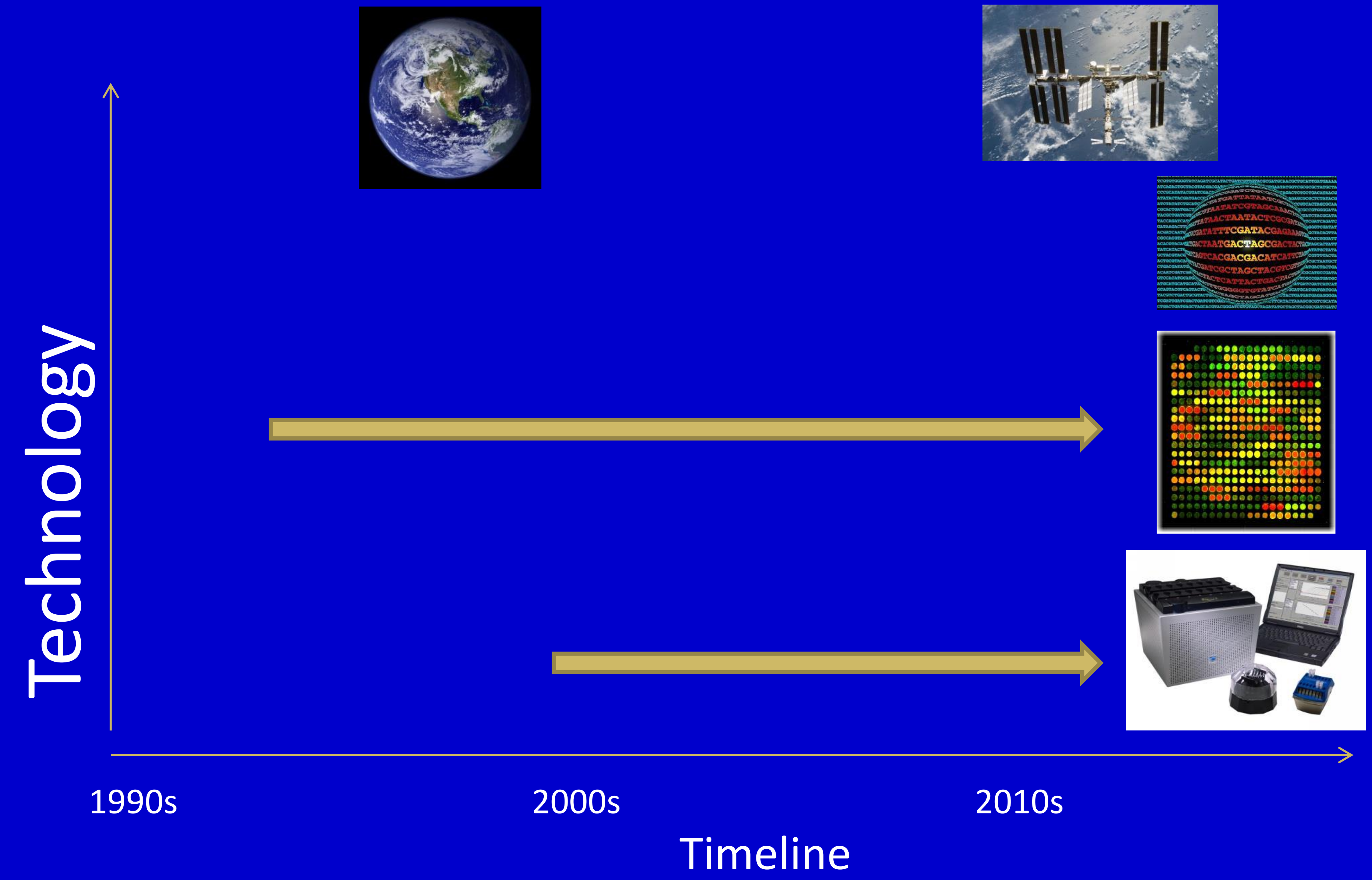
Lag Phase of Space Research



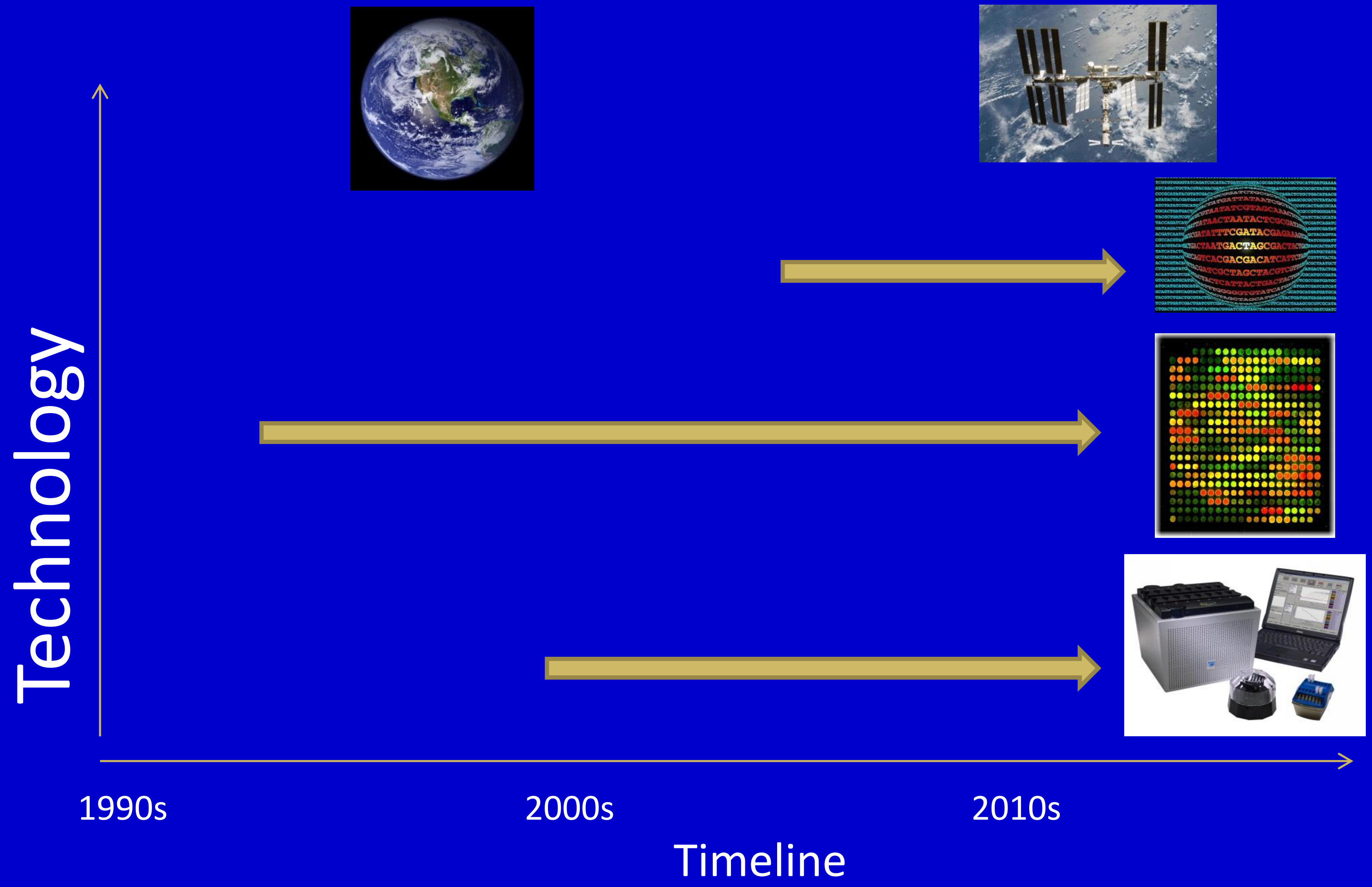
Lag Phase of Space Research



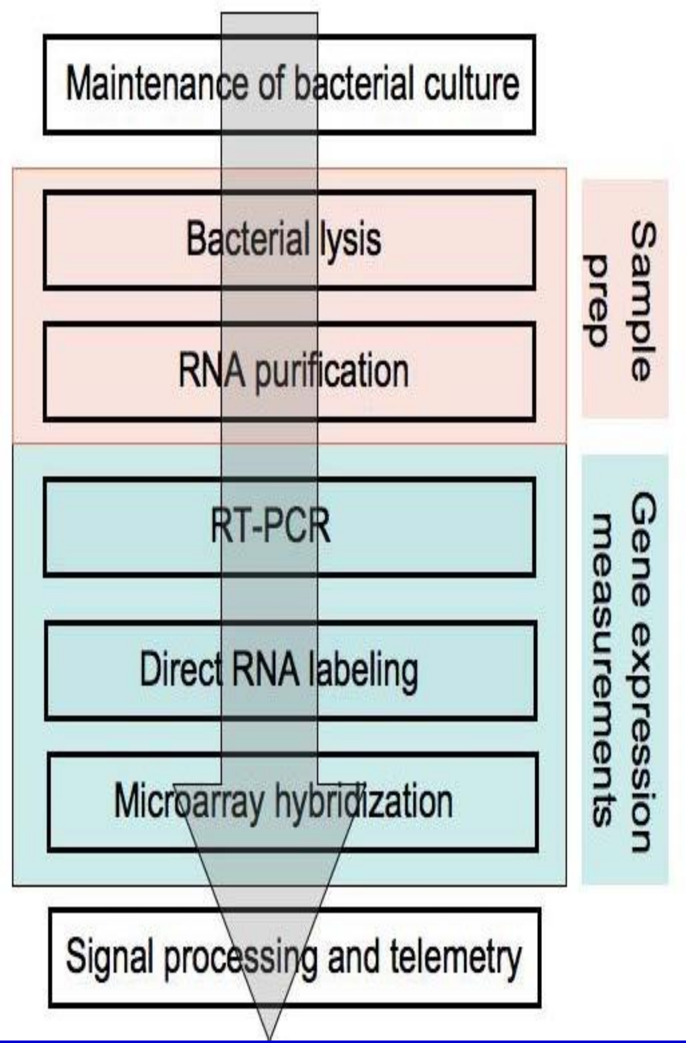
Lag Phase of Space Research



Lag Phase of Space Research



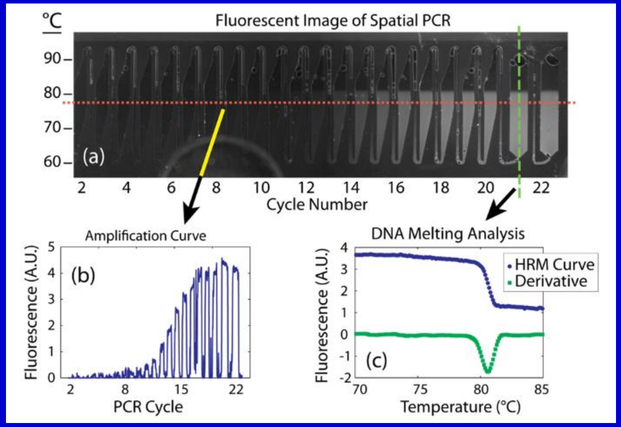
Requirements for Omics Devices for Space Applications :



- Automated
- Reliability
- Small size
- Capability to work independently of the gravity vector
- Low power requirements
- Resistance to shocks and vibrations
- Radiation
- Capability for reuse

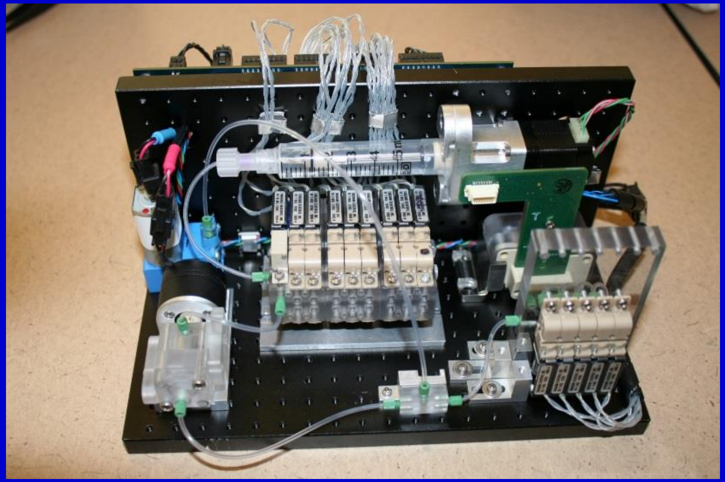
High-throughput Instruments in Space

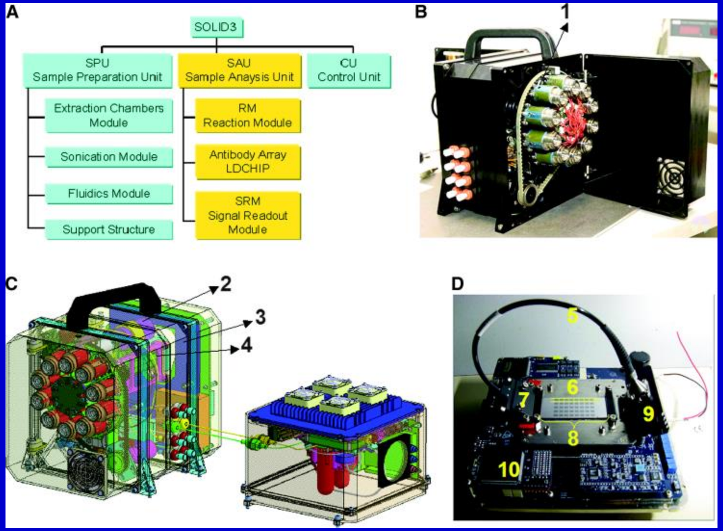
- Nucleic Acids Amplification Technology
  - Continuous-Flow Thermal Gradient PCR (N. Crews/Louisiana Tech)
  - Wetlab2 (ISS Office/NASA Ames)
  - Microbial Detection in Air System for Space (ESA/BioMerieux)



High-throughput Instruments in Space

- Microarray technology:
  – Gene Expression Measurement Module (GEMM) (Pohorille/NASA Ames)
  – Sign Of Life Detector (SOLID) (Parro/Spanish Center of Astrobiology)

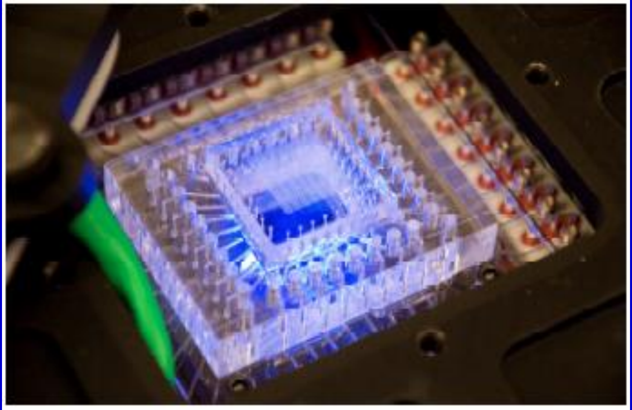




Parro *et al.*, Astrobio. 2011

High-throughput Instruments in Space

- Sequencing Technologies:
  - Search for extra-terrestrial genomes (SETG) (Carr/MIT)
  - Compact and Third Generation Sequencing Technology (Off-the-Shelf)
    - Ion Personal Genome Machine (PGM) (Ion torrent)
    - MiSeq (Illumina)
    - Single-molecule real-time (SMRT) sequencer (Pacific Bioscience)
    - Nanopore (Oxford)



Development Timelines for Space Based Technologies

- Mature Technology: 3-5 years
  - PCR based
  - Microarrays based:
    - Gene expression
    - Phylochip (LBL)
    - LLMDA (#1012)
    - SOLID
- Semi-Mature Technology: 5-8 years
  - RT-PCR based
  - 2nd generation Sequencing
  - Simple Proteomics (microarray or bead technology for limited number of proteins)
- Less Mature Technology: >8 years
  - 3rd generation Sequencing Technology
  - Proteomics (Mass-Spec based)
  - Metabolomics

Commercial- vs. Hybrid- vs. Space-based Platforms

- Commercial based Platform:
  + Current/Advanced Tech
  +Less Development and Testing of Tech
  -Automation
  -Adaptation to Space Conditions (small, resistant, G-level, radiation)
  -Space Qualification
- Hybrid based Platform:
  + Plug and play tech: (use Commercial Technology or hardware and adapt)
  Current/Advanced Tech
  +Quicker Development
  -Moderate testing technology
  -Moderate Adaptation to Space Conditions
  -Moderate Space Qualification
- Space Based Platform:
  + Specifically design and optimized for space related constrains (fluidics, miniaturialization, Automated)
  +versatility
  -Long development and testing of technology,
  -Less advanced technology

Recipe for Deployment for *in-situ* Omics Technology

-Broad Agency/Political drive
-Mature technology
-Multi- and pluri-disciplinary in nature
-Adaptation to the Space Environment
-Miniaturialization /automation
-Supporting Instruments
-Test bed environments for omics platform using Mock-up communities:
    -ISS
    -Nanosatellite in LEO
    -Moon
    -Outside LEO/deep Space (nanosats, secondary payload on deep space missions, etc)
-Sustained research and development, because we often land with situations that there is not enough time to develop appropriate technologies

Acknowledgements

K. Peyvan, Peyvan Systems

O. Santos Orlando, NASA Ames Research Center

A. Pohorille, NASA Ames Research Center and University of California San Francisco

Funding/Support:

NASA Astrobiology Science and Technology Instrument Development, Exobiology Program, and Ames Research Center (OCT), Bioscience Division, and Wyle Laboratory.